Photosynthesis as a Possible Source of Gas Bubbles in Shallow Sandy Coastal Sediments

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LONG-TERM GOALS

Our long-term interests involve the possibility that biological activity can influence acoustic scattering at the water column-seabed interface and the propagation of sound in and over a sandy substrate in a shallow water coastal marine environment. Evidence from laboratory studies clearly demonstrates that gas bubbles can be formed when photosynthesis by benthic microalgae causes pore water in sand collected from the surf zone to become supersaturated with oxygen.

OBJECTIVES

The next logical step is to determine whether this phenomenon occurs in the coastal ocean. The near-term objective of the work is to determine whether photosynthesis (1) produces conditions that lead to the formation of oxygen bubbles in the top few millimeters of shallow sandy coastal sediments, and if it does, how such bubbles change the acoustic reflectivity of the seabed; and (2) whether the timing of the emergence of demersal zooplankton and benthic animals into the water column and their return to the seabed is correlated with changes in light intensity, oxygen concentrations, or bubble abundances.

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14. ABSTRACT
Our long-term interests involve the possibility that biological activity can influence acoustic scattering at the water column-seabed interface and the propagation of sound in and over a sandy substrate in a shallow water coastal marine environment. Evidence from laboratory studies clearly demonstrates that gas bubbles can be formed when photosynthesis by benthic microalgae causes pore water in sand collected from the surf zone to become supersaturated with oxygen.

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APPROACH

In the laboratory, exposure of natural sand from a beach in Panama City, FL, was observed to scatter broadband sound in different amounts throughout a diel cycle (Figure 1).

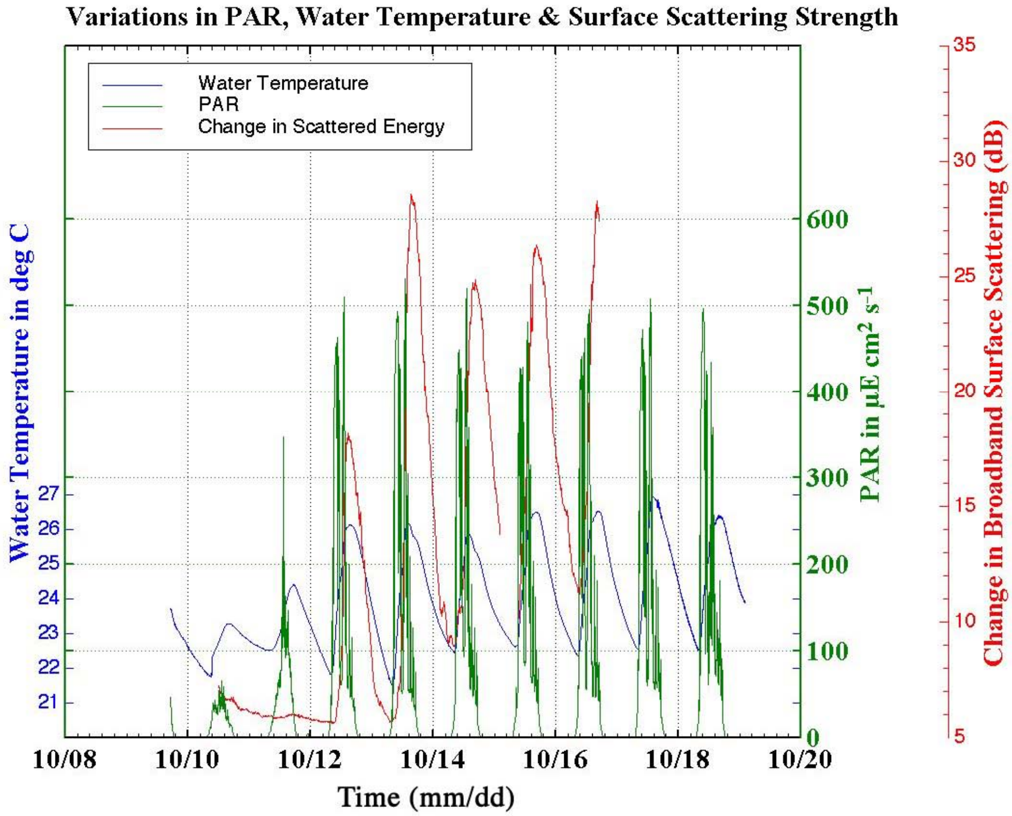

Figure 1: Diel variations in the broadband (100 kHz to 900 kHz) acoustical scattering from a bed of sand (red), the water temperature (blue) and photosynthetically active radiation (green) as measured in a laboratory aquarium exposed to natural sunlight via a neutral density film over a glass window. The resulting light levels simulated a depth of ca. 20 m. Water temperature (blue) was also measured and the changes were determined to be too small to have caused the increases in scattering. The sand was from a beach in Panama City, FL. A 30 dB change in scattering is equivalent to an increase of 1000 times.

The variations in scattered sound were synchronized with, but lagged, diel changes in light levels incident on the bed of sand. Bubbles were observed on the surface of the sand during periods of high scattering. This strongly suggests that photosynthesis created sufficient oxygen to cause supersaturation in the interstitial pores between the sand grains. This eventually led to the formation of small gas bubbles that then migrated to the sediment-water interface, coalescing during and after the migration to form larger bubbles that were visible to the naked eye. The acoustic scattering from the bubbles then caused increases in the broadband scattering from the bed of sand as more bubbles were formed and those present grew in size during the day. In the absence of sunlight, the bubble numbers and sizes were reduced either by release of the bubbles when their growth or buoyancy exceeded the forces keeping them in place on the sand surface or by reabsorption of the gas into the water after oxygen production slowed and finally ceased during the dark hours. Additional details regarding the laboratory experiment can be found in Holliday et al. 2004 and Holliday 2009.

We are preparing to measure incident light levels, oxygen profiles in the top few millimeters of the sediment-water interface, the water temperature, and the acoustic backscattering from the seabed and the water column immediately above the bottom at a shallow site in the coastal ocean. Our objective is to determine whether the phenomenon observed in the laboratory also occurs in the sea. We will examine the backscattering data from the seabed for temporal changes that would be expected should the production of oxygen be sufficient to produce gas bubbles. We will also examine the backscattering from the water column immediately above the sediment-water interface in an attempt to determine the timing of zooplankton emergence in relation to variations in oxygen levels in the near surface sediments.

These measurements will be carried out at a coastal zone site on the north Florida shelf in the Gulf of Mexico (29° 52.169' N, 84° 26.428' W). The station has been occupied previously on numerous occasions by David Thistle and colleagues and is well documented (Teasdale, Vopel, and Thistle 2004). The seabed is a well-sorted, unconsolidated medium sand. Due to the 4 to 5 m depth at this site, storms will occasionally cause sediment re-suspension, and ripple fields can be created. In order to get unambiguous answers regarding the source of any observed change in scattering, we will deploy a camera system to allow us to separate macroscale physical changes in the bottom topography from biological processes that lead to changes in the acoustic reflectivity. We plan to trigger the camera often enough to reveal changes in the Sand Scan tilt angle due to possible settling into the sediment, changes in the ripple field on the seabed, or changes due to possible aggregation of benthic organisms in the field of view for the acoustic sensor.

We also plan to collect several day and night sediment samples from the upper few mm of sand at the site to identify the dominant taxa of benthic microalgae present. These collections should also allow us to identify the dominant zooplankton taxa likely to be participating in vertical migrations should they occur at the study site. (We will also use emergence traps to collect emergers, so their identity can be determined.)

Charles Greenlaw has prepared and is testing the acoustic (Figure 2) and optical instrumentation for this research project. David Thistle from Florida State University (FSU) is preparing the benthic lander (Figure 3) for making oxygen profiles in the sediment, the light sensors, and a temperature recorder all of which will be deployed on the seabed. Dr. Thistle, his lab staff, and the FSU research vessel crew will be deploying all of the instrumentation. They will also collect samples of the sand, phytoplankton, and zooplankton from the seabed. Jan Rines (Graduate School of Oceanography / University of Rhode Island (GSO/URI) will identify the phytoplankton in the samples. Dr. Thistle will examine the

Figure 2: The Sand Scan acoustic sensor consists of a broadband acoustic transducer, a small grey cylinder shown here on a movable arm at the upper left of the instrument. The white pressure case contains the electronics necessary to transmit a sequence of 200 microsecond pulses at several discrete frequencies between ca 0.16 and 0.40 MHz, receive the echoes from a small area on the seabed, and store digital representations of the received bottom reverberation waveforms. The black cylinder contains batteries and the sensor's memory. A white cylinder on the top of the black battery case (partially obscured by a blue mount) protects a thermistor. For scale, the tiles on the lab floor were 1 foot on each side.

Figure 3: Shown here aboard ship, FSU's battery powered, autonomous benthic lander measures oxygen-concentration profiles in unconsolidated sandy sediments. Up to four oxygen probes mounted at the bottom of the black cylinder are mechanically driven into the sediment and measurements are made at sub-millimeter intervals. An internal computer controls a motor via software that is programmed to collect a profile at time and depth intervals specified before the sensor package is deployed on the sea floor. Data are recorded internally and retrieved after the entire sensor package has been recovered. The ring on top of the sensor package is used as a point for attaching a hook or line during deployment and recovery operations. For scale, the black electronics cylinder is ~ 6 inches in diameter.

zooplankton. Van Holliday (URI/GSO) is coordinating the work, and he and Charles Greenlaw (a consultant to URI/GSO) will be analyzing the acoustic and optical imaging data. They will be assisted in the data analysis and interpretation by the other team members, all of whom will participate in preparing such presentations and publications as may be merited based on our results.

WORK COMPLETED

We have modified the SandScan acoustic sensor to provide the capability of echo ranging over a slant range of 1.7 m. The range resolution is now *ca*. 15 cm, depending on the speed of sound near the seabed. The sensor sequentially transmits 200 microsecond pulses at several discrete frequencies between 0.200 and 0.400 MHz. Sufficient battery power and memory has been installed to allow recording of a complete data set every 15 minutes for about a week. The benthic lander has also been refurbished and configured for use in this project. It is currently undergoing its final tests before deployment.

RESULTS

The first of two deployments of this instrumentation will be in late September or early October 2009.

IMPACT/APPLICATIONS

The answers to the questions we are addressing have implications for understanding:

1) The amount and timing of biomass exchanges between the sediments and the overlying water column,
2) the stimuli cueing emergence,
3) the role of bubbles in scouring surficial sediments,
4) the performance of naval sensors used to detect objects on, in, or near the seabed,
5) the characteristics of acoustic communications channels in shallow water,
6) the development of mathematical models for seafloor sound scattering,
7) and the limitations and benefits of acoustic methods now being proposed and used for classifying, describing, and mapping benthic habitats in the littoral zones of many coastal nations.

RELATED PROJECTS

Markus Huettel, one of David Thistle's colleagues at Florida State University, has been funded by ONR to study gas bubbles in near-shore, sandy sediments. In one subproject, he will investigate their distribution along transects in the sub-littoral. We had originally planned to deploy our gear near one of Dr. Huettel's stations in order to independently test the relationship between the acoustic properties of the sediment and the variables he is measuring. The presence of significant amounts of shell hash at those study sites has caused us to change our approach. Should one of the oxygen probes, made of glass, encounter a shell as it is forced into the bottom, it would be broken. Our revised plan is to work at a 5-m site where David Thistle has done oxygen sensor work previously. That site is relatively free of shell fragments. We now plan to supply Dr Huettel with cores from the Thistle site. They will become part of his project, broadening his work in time and space and providing us with additional information about our study site.

REFERENCES

Holliday, D.V., C.F. Greenlaw, J. E. B. Rines, and D. Thistle. 2004. Diel variations in acoustical scattering from a sandy seabed. Proceedings of the 2004 ICES Annual Science Conference, Vigo, Spain. ICES CM 2004/T:01, p. 23 (A). (Full paper on the Conference CD ROM; available on request).

Holliday, D.V. Technology for Evaluating Marine Ecosystems in the Early 21st Century. 2009. Chapter 17 in *The Future of Fisheries Science in North America*, Beamish, Richard J. and Rothschild, Brian J. (Eds.), Springer-Verlag Fish & Fisheries Series, Vol. 31: 293-311, doi:10.1093/icesjms/fsp127.

Teasdale, M., K. Vopel, and D. Thistle. 2004. The timing of benthic copepod emergence. Limnology and Oceanography 49: 884-889.

PUBLICATIONS

Holliday, D.V. Technology for Evaluating Marine Ecosystems in the Early 21st Century. Chapter 17 in *The Future of Fisheries Science in North America*, Beamish, Richard J. and Rothschild, Brian J., Eds. Springer-Verlag Fish & Fisheries Series, Vol. 31: 293-311, doi:10.1093/icesjms/fsp127. [published, refereed.]

Holliday, D.V., P.L. Donaghay, C.F. Greenlaw, J.M. Napp, and J.M. Sullivan. 2009. High-frequency acoustics and bio-optics in ecosystems research. ICES Journal of Marine Science 66: 974-980, doi:10.1093/icesjms/fsp127. [published, refereed.]

Holliday, D.V., C.F Greenlaw and P.L. Donaghay. Acoustic scattering in the coastal ocean at Monterey Bay, CA USA: Fine-scale vertical structures, Continental Shelf Research. [in press, refereed.]